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Delineation of Saltwater Intrusions and Oil Spill Zones Within Stratigraphic Units at Depth in Bakana, Degema L.G.A, Rivers State.

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Abstract
This study examines the subsurface hydrogeological conditions of Bakana in the Niger Delta region, focusing on the impact of hydrocarbon contamination from illegal artisanal refining (kpofire) on groundwater quality and aquifer vulnerability. Electrical Resistivity Tomography (ERT) was employed to map the spatial distribution of conductive zones and assess contaminant migration pathways. The resistivity tomogram revealed a shallow low-resistivity zone associated with hydrocarbon-contaminated fluids, which originated from surface illegal refining activities. Over time, the contaminant plume migrated downward through the porous sandy layers of the Benin Formation, resulting in a continuous conductive anomaly extending to deeper aquifer zones. The high permeability of the Benin Formation, coupled with a shallow water table and direct hydraulic connection to surface systems, facilitates rapid contaminant transport and deep subsurface infiltration. This vertical and lateral spread of contaminants underscores the increasing vulnerability of the aquifer system to hydrocarbon pollution. The findings indicate a clear anthropogenic influence on groundwater quality, contrasting with purely geogenic signatures, and highlight the urgent need for effective environmental regulation and remediation strategies. This study demonstrates the value of ERT in detecting and delineating contaminant plumes in vulnerable aquifer systems, providing a scientific basis for groundwater protection and resource management in Bakana and similar coastal communities.
Keywords: *Bakana, kpofire, hydrocarbon contamination, ERT, Benin Formation, aquifer vulnerability, Niger Delta.*

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I. Introduction

Groundwater is a vital resource in Bakana and other parts of the Niger Delta, where many communities depend on shallow aquifers for potable water. However, increasing anthropogenic activities, particularly illegal artisanal refining (kpofire), have intensified the vulnerability of these aquifers to contamination. Hydrocarbon infiltration into shallow groundwater alters water chemistry, increases ionic concentration, and reduces resistivity, making the subsurface more conductive and less suitable for domestic use (Obenade & Amangabara, 2014; Nwankwoala & Udom, 2011). The hydrogeological structure of the Niger Delta with its highly permeable and porous sandy formations facilitates the vertical migration of contaminants from shallow depths into deeper aquifers. Geophysical techniques such as Electrical Resistivity Tomography (ERT) are therefore essential for mapping subsurface contamination and identifying vulnerable groundwater zones (Loke et al., 2013; Chambers et al., 2014).

It is imperative to take a detail look on the water resources of Iyala Polo's Compound, Bakana, Degema L.G.A., Bakana, Rivers State, because of its expanding population, especially in this coastal region. However, proper management, development, and use of fresh water in coastal areas are necessary to prevent saltwater contamination of existing water supplies. Sound management decisions can be made best when based on available information; therefore, it is desirable to gather as much data as is economically reasonable to support these decisions.

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface and with the view of understanding certain point along the earth surface in which borehole drilling can be done. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the heavy metals, fluid content, porosity and degree of water saturation within the subsurface layers. Electrical resistivity surveys have been used for many decades in hydrogeological (involving borehole drilling activities), mining and geotechnical investigations. More recently, it has been used for environmental surveys.

Extensive exploitation of coastal aquifers that are hydraulically connected to the sea usually results in a reduction in groundwater quality due to seawater intrusion. However, continued groundwater withdrawals, compounded by a decrease in groundwater recharge, can trigger the seawater–freshwater interface to move inland resulting in additional salinization of the coastal aquifer. In this case, coastal aquifers are threatened by an increase in seawater intrusion with sea level rise.

One of the methods of monitoring depths to iron water presence within the subsurface rock layers and saltwater movement in coastal areas is the use of electrical resistivity. This method allows monitoring of a large area at a comparatively small cost. In addition, surface resistivity measurements can be used to give supplemental water quality control in areas between observation wells. The purpose of this study is to investigate using electrical resistivity tools (ADMT: Digital Terrameter, Groundwater Resistivity Meter and Pool Finder Plus) to aid in defining depths to fresh water Aquifers, iron water presence and fresh water/saltwater interface at the subsurface layers of Iyala Polo's Compound, Bakana, Degema L.G.A., Bakana, Rivers State.

Groundwater systems in the Niger Delta are influenced by both natural processes and human activities. The region is characterized by unconsolidated sands, gravels, and clay interbeds of the Benin Formation, which serve as the principal aquifer units. These aquifers are hydraulically connected to surface water bodies and are therefore sensitive to changes in recharge, tidal influence, and subsurface contamination.

Electrical resistivity methods have been widely applied in hydrogeological investigations to delineate aquifer horizons and identify zones of reduced water quality. In Bakana, Degema L.G.A., Rivers State, subsurface resistivity surveys have been used to examine aquifer depths and to detect anomalies associated with saline intrusion and hydrocarbon contamination (Oghonyon, R. et al 2024). Similar investigations in Tombia confirmed saline encroachment at shallow depths, with deeper aquifers remaining relatively fresh (Dickenson, H. D et al 2022).

Recent studies have also demonstrated the diagnostic value of resistivity curve analysis in identifying confined aquifers beneath clay horizons, as observed in Alakahia (Oghonyon, R. 2025). Integrated approaches combining VES and ERT have further enhanced aquifer characterization, as shown in Abuja Campus, Uniport (Oghonyon, R. et al 2025). These findings establish a methodological framework for investigating groundwater conditions in Bakana, where aquifer vulnerability is shaped by both geogenic and anthropogenic factors.

Geologic Setting and Hydrogeology of the Area

The area is within the Niger Delta of Southern Nigeria and it shows an arcuate shape, wave and tide dominated prograding Deltaic system. The sediments range from Eocene to Quaternary. The Niger Delta is basically made up of three Formation such as Benin, Agbada and Akata respectively.

Bakana is situated within the central part of the Niger Delta sedimentary basin, a low-lying deltaic environment dominated by unconsolidated sands, gravels, and clay interbeds of the Benin Formation. This formation, which is Pliocene to Recent in age, has high porosity and permeability and serves as the principal aquifer in the region (Short & Stauble, 1967). The flat topography, shallow water table, and proximity to tidal creeks make the subsurface system highly sensitive to contamination and saltwater intrusion (Reyment, 1965; Short & Stauble, 1967). Aquifers of the Benin Formation (where this work was done as seen in Figure 1) bears the ground water needs of the region, the poorly sorted coastal sands become increasingly sandy and unconsolidated towards the surface. These parameter increases the porosity and permeability and thus, the increase in storage coefficient of the aquifer. Recharge through the surrounding water bodies and extensive rainfall percolating down with a fairly, thick vegetation run-off is negligible, this has resulted in a prolific hydrologic unit within the area.

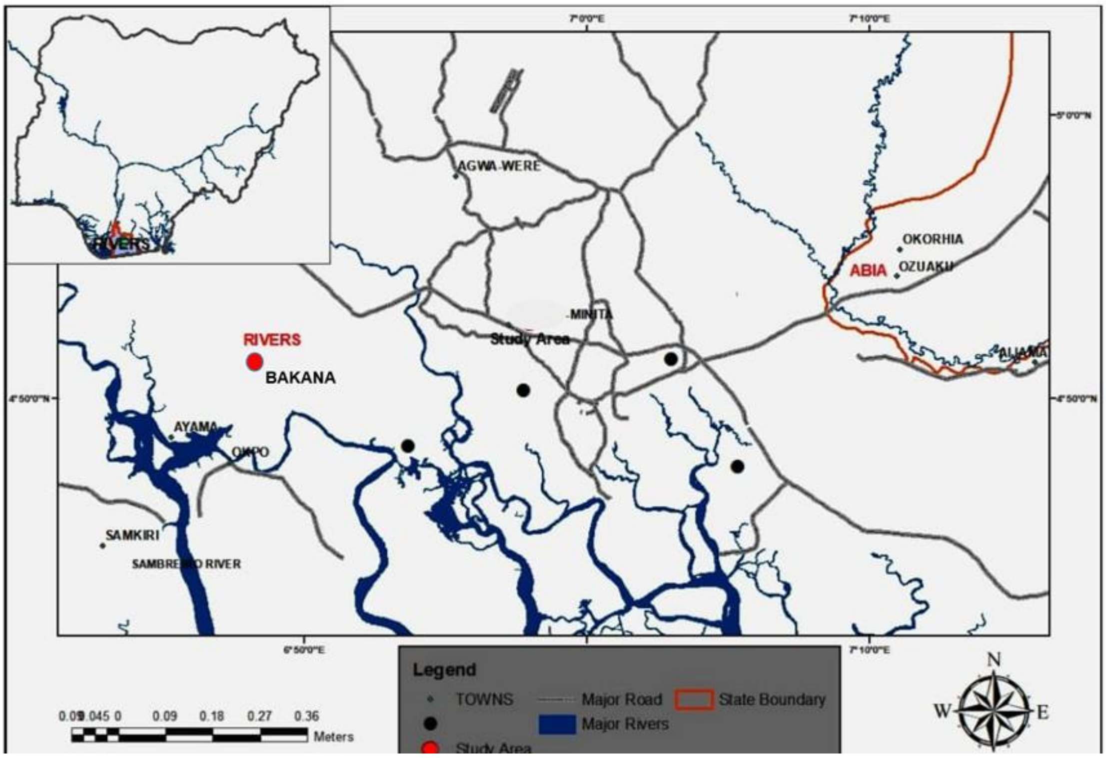

Figure 1: Geologic map of the study area.

II. Methodology

The work involves the use of electrical resistivity method in exploring for Aquifer depths to freshwater Formation for borehole drilling and to evaluate areas within the subsurface layers where saltwater intrusions into freshwater zones occur.

The instrument is connected to the APP through the built-in Bluetooth, so you can use the APP to realize all the operations of the instrument such as measurement signal input, data checking and processing. Using wireless sensor probe, you can complete all the measurements just by walking and stopping. No need long cable, saving time and manpower (Figure 2 and Figure 3).

Many innovative designs make the instruments become more intelligent, efficient and accurate to obtain dozens of invention patents.

ADMT series products are a new generation intelligent prospecting instruments designed by AIDU and Guilin Technology Hydrogeological Investigation Institute. Based on more than 4 decades R&D experiences, we use mobile phone or table PC to run the complicated data calculation to realize the quickly calculation inversion and rapid graph drawing. Then we can quickly draw 2D/3D profile maps, contour maps and curve diagrams by an APP. This is a leap in technology because it makes the complicated geophysical survey becomes easier and simpler. With the APP you could use many intelligent functions such as field measurement control, instantly data process, data cloud backup, online expert analysis and Bluetooth data transaction etc.

Main Features

The main features include:

1. Instant Mapping: Directly drawing the 2D/3D map by the APP after data collection.
2. Simple Operation: Walking and stopping to complete the measurement, so easy.
3. Efficiency: Unique wireless prospecting tech, one person can complete all work, saving time and manpower.
4. Precision: Strong anti-interference ability, field source correction and patent tech to process data.

Figure 2**:** A digital Terrameter for Groundwater Exploration.

Figure 3**:** A Pool Finder Plus for Groundwater Exploration.

Results and Interpretation of Resistivity models.

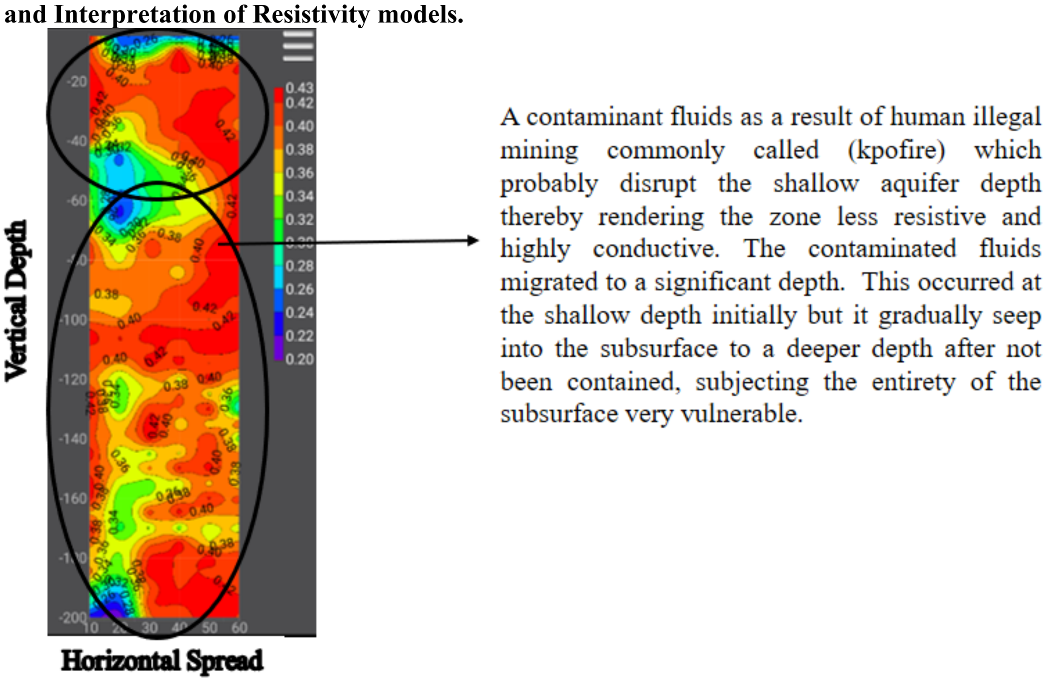

Figure 4**:** A resistivity Tomogram Model of Bakana.

The resistivity tomogram for Bakana reveals a distinct conductive anomaly at shallow depths, which corresponds to the infiltration of contaminant fluids associated with illegal artisanal crude oil refining, locally referred to as kpofire. These illegal activities often involve the discharge of unprocessed hydrocarbon residues and waste products directly into the surrounding soil and water bodies. Over time, these contaminants infiltrate the shallow aquifer zones, increasing the ionic concentration and significantly lowering the resistivity of the formation. As a result, the shallow subsurface becomes highly conductive, indicating zones of compromised water quality.

What began as a localized contamination at shallow depth has migrated downward through the porous and permeable sandy formations of the Benin Formation, which dominate the Niger Delta stratigraphy. The lack of containment and continuous infiltration has allowed these contaminants to gradually seep into deeper subsurface zones, reducing the resistivity of the aquifer system at significant depths. The progressive downward migration indicates that the contaminant plume is not static but actively spreading through connected pore spaces and fractures, increasing the vulnerability of the entire groundwater system.

The hydrogeological setting of Bakana characterized by unconsolidated sands and a shallow water table further exacerbates the contamination risk. These conditions create a direct hydraulic connection between the surface and the aquifer, allowing rapid contaminant transport. The continuity of the conductive zone with increasing depth signifies that the subsurface formation is already compromised and vulnerable to further deterioration if no control measures are put in place.

This situation reflects a classic case of anthropogenic groundwater degradation, where illegal refining has initiated a shallow contamination source that has evolved into a deep-seated aquifer vulnerability. If not mitigated, the downward migration of these fluids may lead to long-term water quality problems, reduced freshwater availability, and increased treatment costs.

III. Summary and Conclusions

The resistivity profile reveals a shallow, low-resistivity zone caused by contamination from illegal artisanal refining activities. Over time, the contaminant fluids have migrated vertically, penetrating deeper aquifer zones. This has resulted in a continuous conductive anomaly through the subsurface, indicating widespread vulnerability of the aquifer system to hydrocarbon pollution.

In conclusion, Illegal artisanal refining (kpofire) has introduced contaminant fluids at shallow depths, creating a highly conductive zone, these contaminants have migrated to deeper depths, compromising aquifer integrity, the subsurface is highly vulnerable to further degradation without immediate remediation and strict environmental control, groundwater monitoring, and containment strategies are urgently needed to protect the aquifer system.

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